Fluvial Systems of the Upper Cretaceous Mesaverde Group and Paleocene North Horn Formation, Central Utah: A Record of Transition from Thin-Skinned to Thick-Skinned Deformation in the Foreland Region

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Synorogenic nonmarine strata of the upper part of the Mesaverde Group and North Horn Formation exposed between the Wasatch Plateau and the Green River in central Utah record a late Campanian tectonic transition in the foreland region from thrust belt deformation to basement-cored uplift. Thick Mesaverde sections in the Wasatch Plateau on the west and the Book Cliffs near the Green River on the east are separated by the San Rafael Swell, a basement uplift across which the late Campanian section is thinned by erosion. The sedimentary sequence in the Wasatch Plateau was deposited by east- and northeast-flowing braided and meandering rivers. Time-equivalent sections in the east comprise a lower sequence of mixed braided fluvial, tidal flat, and marine deposits overlain by an upward-coarsening sequence that grades upward from meandering river deposits to pebbly braided river deposits. Paleocurrent data indicate that rivers of the lower sequence flowed eastward, while those of the upper sequence flowed northeastward.

Sandstones in the upper part of the Mesaverde Group can be divided into two distinct compositional suites, a lower quartzose and an upper lithic petrofacies, which aid in lithostratigraphic correlation across the San Rafael Swell. Lithic grain populations of the upper petrofacies are dominated by sedimentary rock fragments on the west and volcanic rock fragments on the east. Sedimentary lithic grains were derived from the thrust belt, while volcanic lithic grains were derived from a more distant volcanic terrane to the southwest. Tributary streams carrying quartzose detritus from the thrust belt entered the main northeast-flowing trunk system and caused a basinward dilution of volcanic detritus. During most of Campanian time, sediment transport was eastward and northeastward away from the thrust belt. Simultaneous disappearance of volcanic grains and local changes in paleocurrent directions at the top of the section reflect a change of drainage patterns in latest Campanian time that marked initial growth of the San Rafael Swell and possibly other thick-skinned uplifts to the south. Depositional onlap across the Mesaverde Group by a largely posttectonic assemblage of fluvial and lacustrine strata (North Horn Formation) indicates a minimum age of late Paleocene for uplift of the San Rafael Swell.

INTRODUCTION

The Mesaverde Group, exposed on the east flank of the Wasatch Plateau and the Book Cliffs (Figure 1), forms a progradational clastic wedge at the top of the Upper Cretaceous section in central Utah. Deposition occurred in an eastward-thinning foreland basin that lay parallel to an active thrust belt on the west. The Mesaverde Group coarsens upward from siltstone and sandstone deposited in delta front and delta plain settings (Flores and Marley, 1979; Balsley, 1980) into a sandstone-dominated sequence deposited in fluvial environments (Van De Graaff, 1972; Keighin and Fouch, 1981; Fouch et al., 1983). Most of the sandstone within the fluvial section represents detritus shed eastward from thrust-related uplift of the Sevier orogenic belt (Spieker, 1946; Harris, 1959; Armstrong, 1968). However, changes in dispersal direction, sandstone composition, and depositional patterns within the

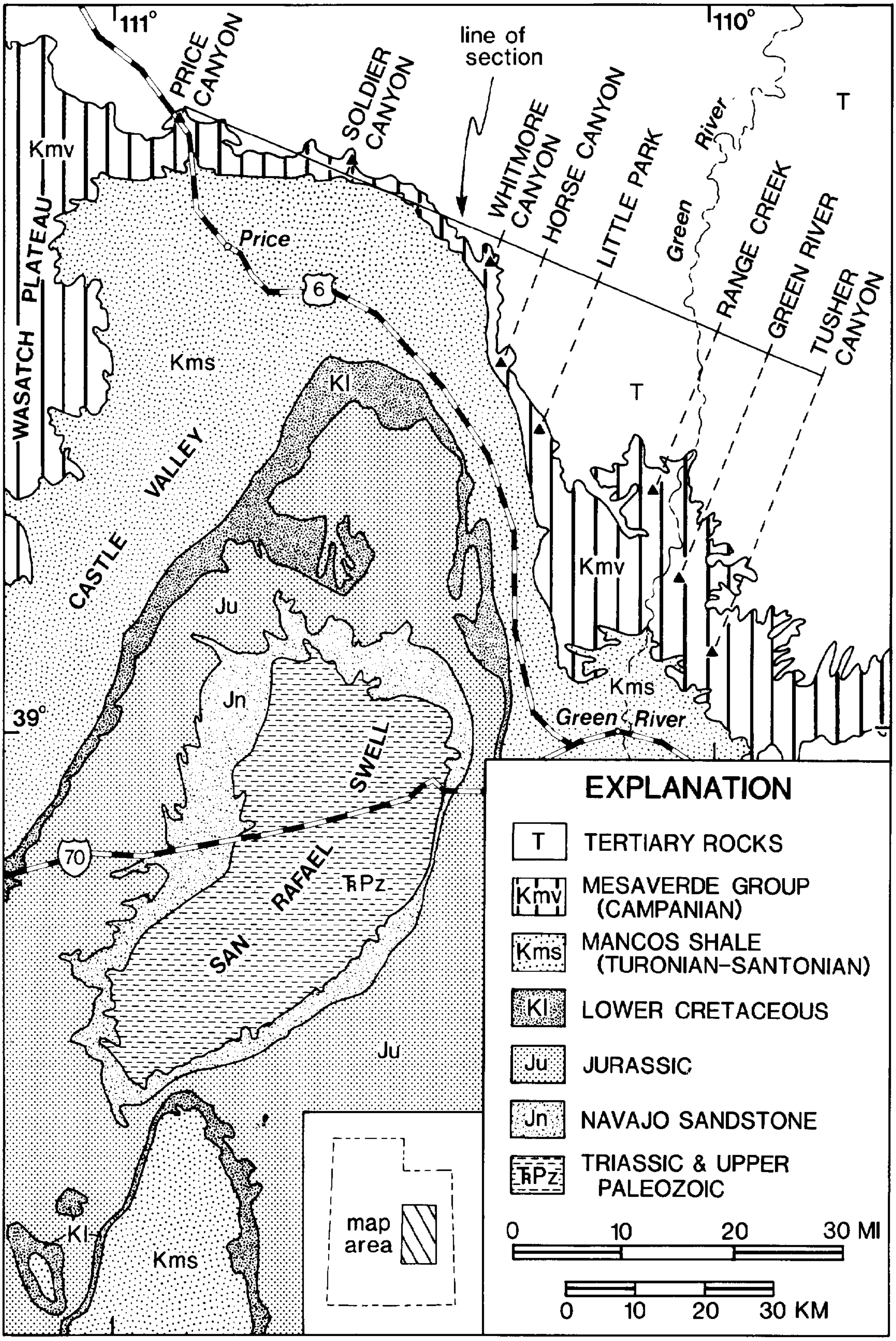

Figure 1—Map of Book Cliffs study area, showing locations of measured sections. Cross section line, onto which stratigraphic thicknesses of Figure 11 are projected, is indicated by the solid south-southeast-trending line. Kms includes the Dakota Sandstone of Late Cretaceous age. Joes Valley location lies 8 km (5 mi) west of the western map boundary where the Wasatch Plateau runs off the map.

uppermost part of the Mesaverde Group reflect an eastward shift in deformation from the thrust belt to basement-controlled uplift within the foreland basin in latest Campanian time.

The Mesaverde Group is exposed nearly continuously along cliffs that run eastward from the Wasatch Plateau and then southeastward to the Green River (Figure 1). The exposures thus provide an extensive section almost parallel to the dominant dispersal direction of the Late Cretaceous fluvial systems and permit sedimentologic analysis over a broad region. Stratigraphic and sedimentologic relationships in the upper part of the Mesaverde Group within the study area (Figure 1) define the timing of basement uplifts within the basin and shed light on latest Cretaceous paleogeography in central Utah.

Patterns of deposition recorded by the Upper Cretaceous–Paleocene section in the Wasatch Plateau suggest that the San Rafael Swell, a thick-skinned plateau uplift, existed by Maestrichtian time (Fouch et al., 1983). Stratigraphic, sedimentologic, and petrographic data presented here document that the earliest growth of the San Rafael Swell, and probably two other related uplifts, the Circle Cliffs uplift and the Monument upwarp, occurred in latest Campanian time. The data represent a refinement of previous Laramide age assignments for the block uplifts of the Colorado Plateau (Kelley, 1955; Davis, 1978).

STRATIGRAPHIC RELATIONSHIPS OF THE UPPER MESAVERDE GROUP AND NORTH HORN FORMATION

Formations of the upper Mesaverde Group described in this study are shown in Figure 2. The lowermost unit of the fluvial sections in both the western and eastern part of the study area is the Castlegate Sandstone. The Castlegate rests sharply on the Blackhawk Formation throughout the area, and the contact has been interpreted as disconformable as far east as the Green River (Spieker, 1946; Fouch et al., 1983). The hiatus (if one exists), however, is of short duration based on faunal evidence (Fouch et al., 1983). The contact may represent an abrupt change from delta plain to sandy alluvial plain sedimentation that resulted as the Castlegate fluvial system overrode the Blackhawk delta as both environments prograded eastward.

Spieker (1946) recognized that the North Horn Formation overlying the Mesaverde Group preserves a record of continuous deposition across the Cretaceous–Tertiary boundary in the central Wasatch Plateau. He inferred the contact of the North Horn and underlying Price River formations to be gradational as well. More recent work has shown, however, that the contact is unconformable (Fouch et al., in press). Where it is exposed throughout the Wasatch Plateau and eastward, the contact is marked by intense bleaching and limonitization of the underlying sandstone. Large rootlet traces are locally present in coarse-grained sandstone underlying the contact. Plagioclase grains are extensively argillized and kaolinite is often pseudomorphous after the grains in the upper few tens of meters of the Price River and Tuscher formations. Where pebbly lithologies occur high in the Cretaceous section, particularly in exposures of the Tuscher Formation near the Green River, lags of reworked pebbles are present at the base of the North Horn Formation. Elsewhere in the study area east of the Wasatch Plateau the basal North Horn lacks extraformational pebbles. Palynomorph and faunal assemblages indicate a hiatus at the contact, as discussed in a later section.

Nomenclature

The stratigraphic terminology used here is basically that of Fisher et al. (1960) as amended by Fouch et al. (1983). The nomenclature used for the eastern facies (Figure 2) is carried westward from the Green River, through lateral facies changes and unit pinchouts within the Tavaputs Plateau, to the approximate axis of the San Rafael Swell at Soldier Creek (Figure 1). The swell is a structural boundary west of which relationships in the Castlegate–Bluecastle section are difficult to trace because of poor exposure and difficult access. The post-Bluecastle section beneath the hiatus at the base of the North Horn Formation is almost entirely absent at Soldier Creek (Fisher et al., 1960). Direct surface correlation of post-Bluecastle beds in the Price River Formation with its age equivalents farther east is thus impossible across the axis of the San Rafael Swell.

Age and Correlation

The absolute ages of zone fossils that bracket the fluvial section are taken from the chronostratigraphic correlations of Fouch et al. (1982, 1983) (Figure 3), which utilize new decay constants for radiometric age determinations. Because the units are largely of fluvial origin, direct molluscan age control is sparse. The section between the base of the Castlegate Sandstone and the top of the Bluecastle Tongue of the Castlegate was deposited during the time spanned by the zones of *Baculites asperiformis* and *Exiteloceras jennyi* (74–79 m.y.). Extensive palynomorph data (Fouch et al., 1983) indicate that the post-Bluecastle section ranges in age from middle late to latest Campanian (approximately 73–74 m.y., ending within the *B. cuneatus* zone), and provide the basis for correlations of post-Castlegate Cretaceous rocks in Price Canyon with the section east of the San Rafael Swell.

The upper part of the Mesaverde Group is thus equivalent to the upper member of the Sixmile Canyon Formation of the Indianola Group, as defined by Lawton (1982) (Figure 3). The Sixmile Canyon Formation is in part Santonian and in part Campanian in age (Fouch et al., 1982). The upper Tuscher Formation is probably equivalent to the Ohio Creek Member of the Hunter Canyon Formation of western Colorado (Johnson and May, 1980). Rocks equivalent to the Tuscher to the southwest in the Kaiparowits region probably include part of the Kaiparowits Formation and the Canaan Peak Formation (Bowers, 1972).

The North Horn Formation, which unconformably overlies the Mesaverde Group, varies widely in age and lithic character (Figure 3). A Maestrichtian age for basal North Horn strata in Price Canyon is based on freshwater molluscs, ostracodes, and pollen (Fouch et al., in press). Near the Green River, North Horn strata are indicated to be of late Paleocene age on the basis of freshwater molluscs, ostracodes, and pollen (Fouch et al., 1982; T. D. Fouch, personal communication, 1982). The base of the North

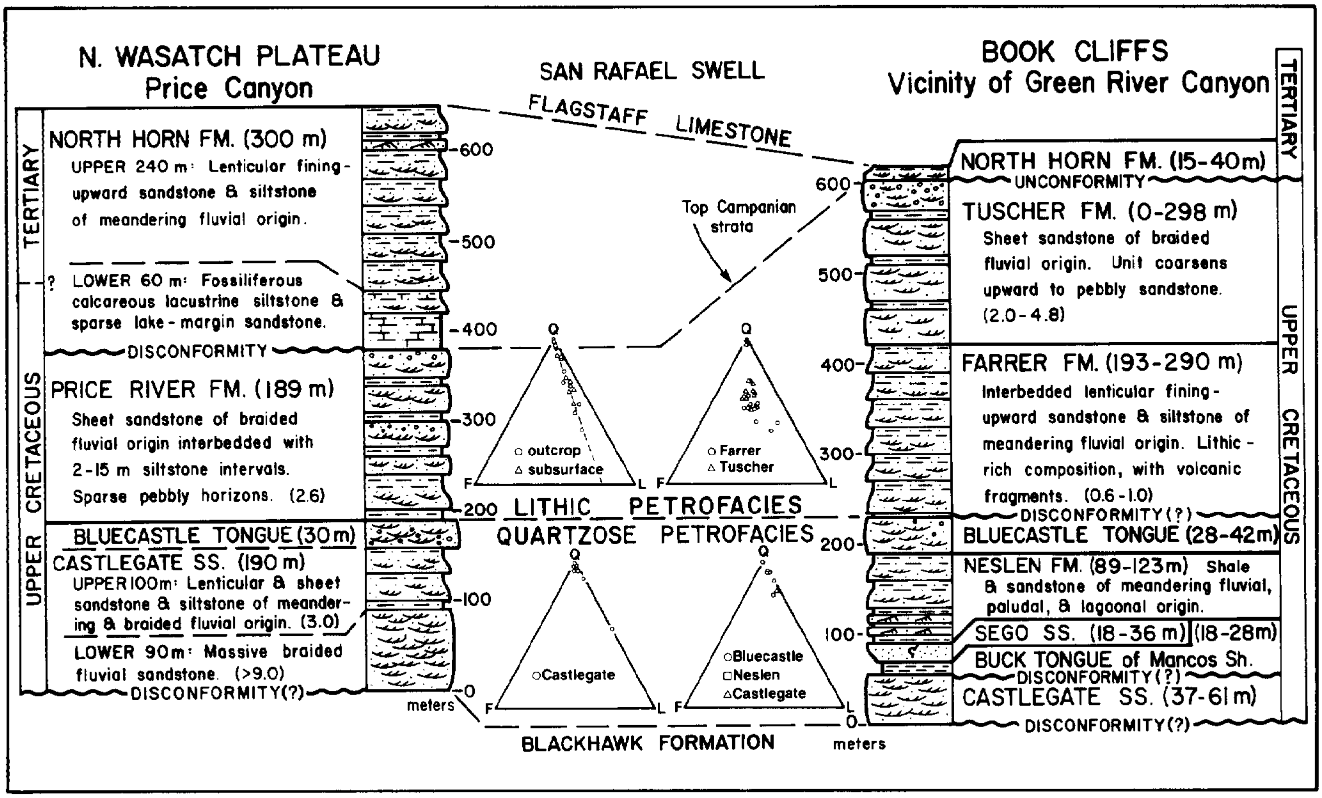

Figure 2—Stratigraphy and sandstone composition of upper Mesaverde Group strata west and east of the San Rafael Swell. Numbers in parentheses are sandstone/(sandstone + siltstone) values for the units. At all localities, the Bluecastle is a tongue of the Castlegate Sandstone (Fouch et al., 1983). Used with permission of the Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section.

Horn Formation is thus time transgressive, becoming younger to the east. The hiatus separating Cretaceous and Tertiary rocks east of the San Rafael Swell represents at least 15 m.y. (Fouch et al., 1982).

Stratigraphy

Castlegate Sandstone

The Castlegate Sandstone, as used in this study, follows the usage of Spieker (1931). At its type locality in Price Canyon, the Castlegate Sandstone includes a lower massive sandstone, which forms a continuous cliff throughout the study area, and an upper sequence of interbedded sandstone and siltstone, which forms ledgy outcrops (Spieker, 1931). The entire unit is 190 m (623 ft) thick and is capped by a ledge of pebbly coarse-grained sandstone 20–30 m (66–98 ft) thick. The lower cliff-forming unit (the Castlegate Sandstone of Van De Graaff, 1972) thins eastward from 90 m (295 ft) in Price Canyon to 37 m (121 ft) in Tusher Canyon, and it has been tentatively recognized as a unit 17–20 m (56–66 ft) thick on the northeastern flank of the Uinta basin (Gill and Hail, 1975). Above the cliff-forming unit, the ledge-forming sequence grades eastward into the Neslen Formation as shown by palynomorph data (Fouch et al., 1983) and petrographic data. The uppermost pebbly unit of the Castlegate grades eastward into the Bluecastle Tongue of the Castlegate Sandstone east of the San Rafael Swell (Figures 2 and 3) and is tentatively recognized here as the Bluecastle Tongue in Price Canyon. The Castlegate–Price River contact intersects the floor of Price Canyon at the mouth of Sulphur Canyon (SE¼, sec. 22, T. 12 S., R. 9 E., Kyune, Utah 7.5′ quadrangle).

The lower cliff-forming part of the Castlegate Sandstone consists of lenticular sandstone bodies or bedsets dominated by trough cross beds, tabular bedsets with planar cross beds and slightly inclined plane beds, and thin inclined interbeds of sandstone and siltstone. The lenticular and tabular sandstone bedsets range from 15 cm to 2.5 m (0.5–8 ft) thick. The lenticular bedsets rest on erosive bases and form stacked sequences. Large coaly plant fragments, including tree branches and trunks, and intraformational clasts of mudstone and siltstone are abundant. The tabular bedsets have sharp bases and are often found in stacked sequences of two or three beds above a complex of lenticular beds. The inclined interbeds of sandstone and siltstone range from 2 to 30 cm (1–12 in.) thick and contain ripples, climbing ripples, horizontal lamination, and contorted lamination. Siltstones are typically horizontally laminated and rippled; macerated plant debris is common. The thin interbeds of sandstone and siltstone occasionally form sequences 10 m (33 ft) or more thick and continuous for over 100 m (305 ft) laterally (Figure 4). The thin beds of sandstone and siltstone occasionally grade vertically or interfinger laterally into extensive massive to mottled dark gray siltstones with coal fragments and rare silicified bone fragments. Sometimes the inclined beds of siltstone and sandstone fill broad

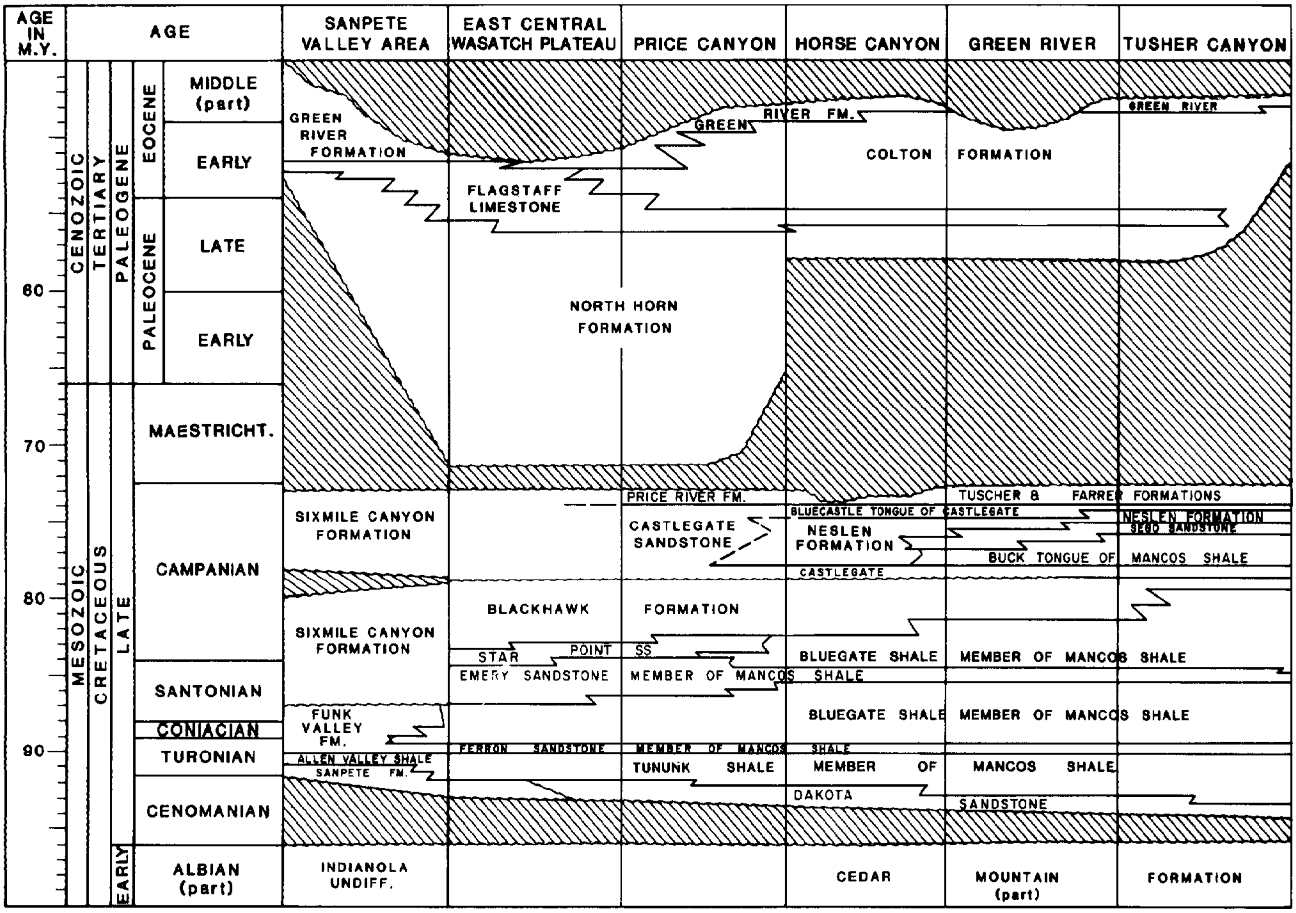

Figure 3—Time-stratigraphic chart showing nomenclature and correlation of upper Albian to middle Eocene rock units from Sanpete Valley in central Utah east to Tusher Canyon. Modified from Fouch et al. (1983). Used with permission of the Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section.

channelform depressions up to 10 m (33 ft) deep and 50 m (165 ft) across. Other times they are truncated beneath a sequence of trough cross-bedded sandstone bodies. The sandstone within the Castlegate Sandstone is dominantly fine to medium grained in Price Canyon and very fine to fine grained in eastern exposures. Pebble lags and tree trunks are common in the formation at Joes Valley (see Figure 5 for location) and indicate a grain size increase southwestward along the Wasatch Plateau.

The sequences and structures in the Castlegate Sandstone are similar to the vertical sequence described by Cant and Walker (1978) for the sandy braided South Saskatchewan River. The lenticular bedsets of trough cross beds represent channel complex deposits, and the tabular beds with low-angle lamination and planar cross beds represent sand flat deposits formed by amalgamation of large transverse and longitudinal bars (T. R. Clifton, personal communication, 1984). The thinly bedded sandstone and siltstone beds probably represent splay deposits into abandoned channels, as represented by the fill of channelform depressions, and on floodplains, as represented by lateral gradation into mottled siltstone deposits. The regional geometry of the Castlegate Sandstone indicates that it was probably deposited by many different rivers on a sandy alluvial plain that paralleled the general trend of the Campanian shoreline (Van De Graaff, 1972). Paleocurrent data indicate consistent east–southeast sediment transport within the lower cliff-forming part of the Castlegate Sandstone (Figure 5).

The upper part of the Castlegate Sandstone in Price Canyon, which forms ledges below the Bluecastle Tongue, is dominated by trough cross-bedded, fine-grained sandstone beds 2-5 m (7-16 ft) thick and rich in mudstone ripup clasts and large plant fragments. The beds grade up into interbeds of very fine grained sandstone and siltstone with depositional dips as high as 15°. The inclined beds are overlain in turn by sequences of poorly exposed gray siltstone and dark brown carbonaceous shale. Thin, very fine grained sandstone beds 1 m (3 ft) and less thick occur in the siltstone and shale sequences. The sandstone beds contain ripple lamination or are massive due to bioturbation. Rootlet traces and small plant fragments are common, and bed bases are sharp and, in places, load casted.

The upper ledge-forming part of the Castlegate Sandstone is interpreted to have been deposited in a meandering stream environment. The trough cross-bedded sandstones probably represent channel and lower point bar deposition, while overlying inclined units of finer sandstone and siltstone were deposited by lateral migration of point bars. Thin-bedded sandstone beds in the silty floodplain sequences represent crevasse splay deposits.

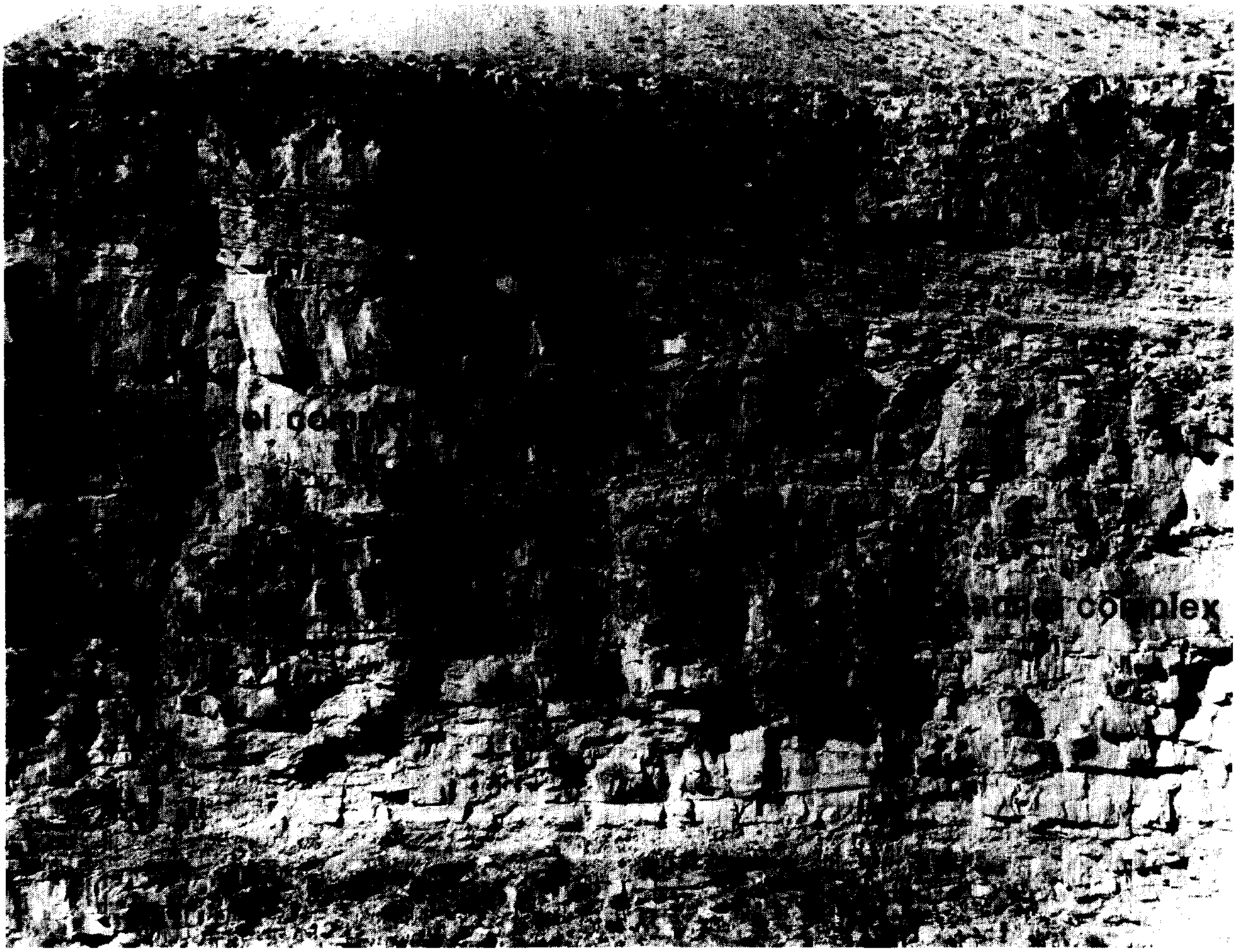

Figure 4—Upper 32 m (105 ft) of the Castlegate Sandstone exposed on the west wall of Green River Canyon. Thinly bedded lateral accretion or splay deposits at extreme base of photo and near top of unit alternate with irregularly bedded, dominantly trough cross-bedded (channel complex) sandstone of braided fluvial origin. Unit composed of inclined beds at top is approximately 4.5 m (15 ft) thick.

Buck Tongue of Mancos Shale and Sego Sandstone

The Buck Tongue of the Mancos Shale consists of 20–28 m (66–92 ft) of thinly bedded, medium gray siltstone and mudstone and tan, very fine grained sandstone that overlie the Castlegate Formation at the Green River and Tusher Canyon localities (Figure 1). I have placed the basal contact in this study at a horizon of nodular hematitic mudstone and chert continuous between the above localities and thought to be a paleosol horizon developed above the Castlegate. The unit thins westward and pinches out between the Green River and Horse Canyon localities (Fisher et al., 1960) (Figure 3). Time-equivalent strata lie beneath present levels of exposure at Range Creek. At the Green River and Tusher Canyon localities, the Buck Tongue grades vertically into an upward-thickening and -coarsening sequence of very fine grained sandstone and siltstone of the overlying Sego Sandstone. Thin beds low in the sequence are capped by 3–5 m (10–16 ft) of very fine to fine-grained, well-sorted sandstone. The thinly bedded sandstone contains hummocky stratification and ripple lamination, while a thick (4 m [12 ft]) sandstone capping the upward-coarsening cycle contains trough cross beds and occasional tabular cross beds. *Ophiomorpha* is present in the sandstone, which is overlain by wavy bedded sandstone and siltstone containing oyster shells. A similar but thinner upward-coarsening sequence overlies the described sequence (Lawton, 1983).

The Sego Sandstone was apparently deposited in transition zone to middle and upper shoreface environments (Harms et al., 1975; Balsley, 1980) by progradation of subaqueous bars across the Mancos shelf. Fossiliferous tidal flats that lay landward of the bars subsequently prograded across the bar deposits. The cycles, and thus the bar heights, are 10–12 m (33–39 ft) thick and contrast sharply with similar cycles in the older Blackhawk Formation, which are 25 m (82 ft) thick (Balsley, 1980; Lawton, 1983).

Neslen Formation

The Neslen Formation was defined by Fisher (1936) to include coal-bearing strata above the Sego Sandstone. He considered it to be a member of the Price River Formation.

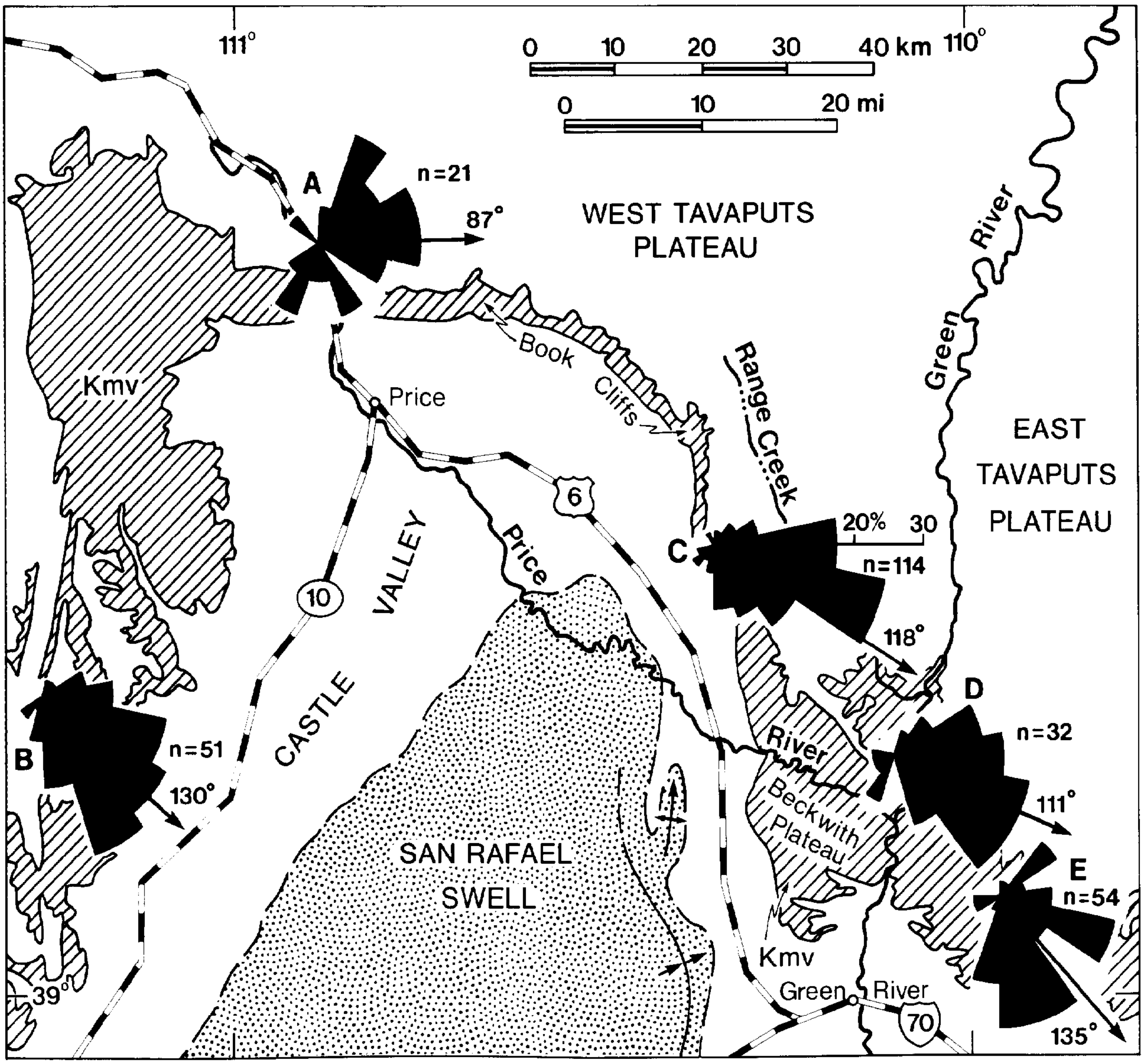

Figure 5—Paleocurrent data for lower part of Castlegate Sandstone (see also Van De Graaff, 1972). All measurements from axes of trough cross bedding. Localities: A. Price Canyon; B. Joes Valley; C. Horse Canyon; D. Green River; E. Tusher Canyon. Ruled area (Kmv) shows outcrop area of Mesaverde Group rocks of this study.

The unit was given formational status by Cobban and Reeside (1952), but was first formally raised to formational rank by Fisher et al. (1960).

The basal contact of the Neslen Formation is gradational at the Green River and Tusher Canyon localities. It is placed above the uppermost upward-coarsening sandstone cycle of the Sego Sandstone where the latter is present (Fisher et al., 1960). At Horse Canyon, where both the Buck Tongue and the Sego Sandstone are absent, the basal Neslen contact is arbitrarily placed at the top of the cliff-forming Castlegate Sandstone. Fisher et al. (1960) considered the unit above the Castlegate at Horse Canyon to be the Price River Formation, although the beds grade westward into strata of the upper part of the Castlegate Sandstone (described previously). The presence of thin coal beds, gastropod-bearing sandstone, and flaser bedded mudstone and sandstone at Horse Canyon render the interval lithologically more like the Neslen Formation of Fisher (1936) than the thick interbeds of sandstone and siltstone of the upper part of the Castlegate farther to the west. Consequently, the stratigraphic interval between the Castlegate Sandstone and the Bluecastle Tongue of the Castlegate in the region between the Green River and Horse Canyon is considered to be the Neslen Formation for purposes of this study (Figure 3). The unit is probably disconformable above the Castlegate, which is based on the evidence for paleosol development farther east.

The Neslen Formation consists of roughly 50% siltstone, which is commonly associated with wavy bedded and flaser bedded sandstone, burrowed and rooted lenticular sandstone beds as thick as 1 m (3 ft), and stringers of coal. Channelform, very fine to fine-grained sandstone beds 2–7.5 m (6.6–25 ft) thick are interbedded with the siltstone. The sandstone beds are characterized by scoured basal contacts and abundant mudstone clasts, and they grade upward into inclined beds of sandstone 30–100 cm (12–40 in.) thick separated by siltstone beds as much as 10 cm (4 in.) thick. Burrows are common in sandstones, and load casts are present locally.

The Neslen Formation was apparently deposited dominantly on a coastal plain of low relief. As interpreted here, the unit forms a regressive sequence consisting of tidal flat deposits near its base, passing up through possible distributary sandstone, into a section dominated by meander belt deposition. Meandering streams are suggested by common inclined lateral accretion deposits above the channel sandstone beds, and frequent burrowed and rooted crevasse-splay deposits in the siltstone sequences. The westward transition of coeval Neslen and upper Castlegate depositional environments from tidal flat to meander belt deposits records a lateral coarsening of lithologies toward the Sevier orogenic belt.

Bluecastle Tongue of Castlegate Sandstone

The Bluecastle Tongue gradationally overlies the Neslen Formation and has a relatively uniform thickness between 30 m (98 ft) (Price Canyon) and 42 m (138 ft) (Range Creek) within the study area, but thins farther to the east (Fisher, 1936). The Bluecastle of the study area separates the Neslen and Farrer formations. Farther east, however, beds above the Bluecastle have been included in the Neslen Formation (Fisher, 1936; Cobban and Reeside, 1952; Fisher et al., 1960).

The Bluecastle Tongue forms a persistent ledge in the eastern part of the study area. The unit weathers light brown and creates a distinctive marker horizon in the vicinity of the Green River. The Bluecastle Tongue contains abundant lenticular beds of trough cross-bedded sandstone and thin inclined beds of siltstone and sandstone similar in aspect to the bedding present in the lower Castlegate Sandstone. Consequently, the units are very similar in appearance. Inclined interbeds of sandstone and siltstone become more common eastward. West of the Green River trough cross-bedded sandstone dominates the Bluecastle, which is interrupted locally by broad lenses of siltstone and mudstone as thick as 5 m. Tabular sandstone bedsets with plane laminated beds dipping 15° or less and tabular cross beds are present but less common than in the Castlegate Sandstone. Rootlet marks are common in sandstone bed tops. The Bluecastle is coarser grained than the massive lower Castlegate and consists of poorly sorted, fine- to coarse-grained sandstone at all localities. Pebbles of chert, very fine grained quartz arenite, and punky gray claystone are common in western localities but become sparser eastward. Maximum pebble size is 15 mm at Price Canyon and 4 mm (0.2 in.) at Tusher Canyon.

Like the Castlegate Sandstone, the Bluecastle Tongue was deposited on a fluvial coastal plain. The presence of siltstone and mudstone lenses interpreted to have been deposited in abandoned channels and fewer unambiguous transverse bar deposits suggests that Bluecastle streams may have been sinuous, even meandering. Inclined sandstone and siltstone beds may represent lateral accretion of point bar deposits rather than splays, as interpreted in the Castlegate Sandstone. Mean vectors on trough cross-bed axes in the Bluecastle Tongue are consistently northeast-directed at all localities (Figure 6).

Price River Formation

The Price River Formation originally included all Upper Cretaceous strata above the Blackhawk Formation (Spieker and Reeside, 1925; Clark, 1928). The unit is now defined as a section of ledge-forming sandstone and siltstone 189 m (620 ft) thick between the Castlegate Sandstone and the North Horn Formation in Price Canyon (Fouch et al., 1983; Lawton, 1983). Its basal contact is probably conformable, but its upper contact with the North Horn Formation is disconformable.

The lower half of the unit consists of continuous sheetlike sandstone beds interbedded with siltstone intervals. The section is approximately 75% sandstone (Lawton, 1983). Sandstone beds range from 10 to 15 m (33–48 ft) thick and consist of poorly sorted, medium-grained sandstone. Grain sizes fine upward slightly within individual sandstone sheets, which are dominated by trough cross beds. Chaotic mudchip lags are common near the bases of the sandstone beds, and ripple lamination is occasionally present near bed tops. The sheetlike sandstone beds occasionally terminate laterally in gently dipping sandstone and siltstone beds adjacent to poorly exposed lenses of siltstone and shale. The sandstone beds grade upward into poorly exposed siltstone intervals.

Sheetlike sandstones of the upper half of the Price River Formation in Price Canyon tend to be thicker and coarser than sandstone horizons of the lower half. Fining-upward cycles within the sheets range from 15 to 20 m (48–66 ft) thick and sometimes merge to form beds as thick as 30 m (98 ft). The beds commonly have rooted tops and grade rapidly into siltstone intervals 5–13 m (16–43 ft) thick. Planar cross beds are present in the sequences but are subordinate to trough cross beds. In contrast to underlying beds, the uppermost sandstone unit in Price Canyon is pebbly, contains abundant scour-and-fill structures, and lacks a distinct fining-upward trend. Measurements of trough cross bed axes throughout the Price River Formation indicate northeastward transport of sandstone deposited in Price Canyon (see Figures 7 and 8).

The dominance of trough cross beds, fining-upward trends, and inclined lateral accretion beds adjacent to abandoned channel plugs indicates that the Price River Formation was most likely deposited by sinuous to meandering rivers. The thickness of the fining-up sheet sandstones suggests that the rivers ranged from 10 to 20 m (33–66 ft) deep, using the channel depth criteria of Leeder (1973). The rivers flowed northeast on a broad alluvial plain that extended eastward into Colorado (Fouch et al., 1983). The uppermost pebbly sandstone bed may represent a shift to braided fluvial deposition in the Price Canyon area.

Farrer Formation

The Farrer Formation was defined as a member of the Price River Formation by Fisher (1936), and formally raised

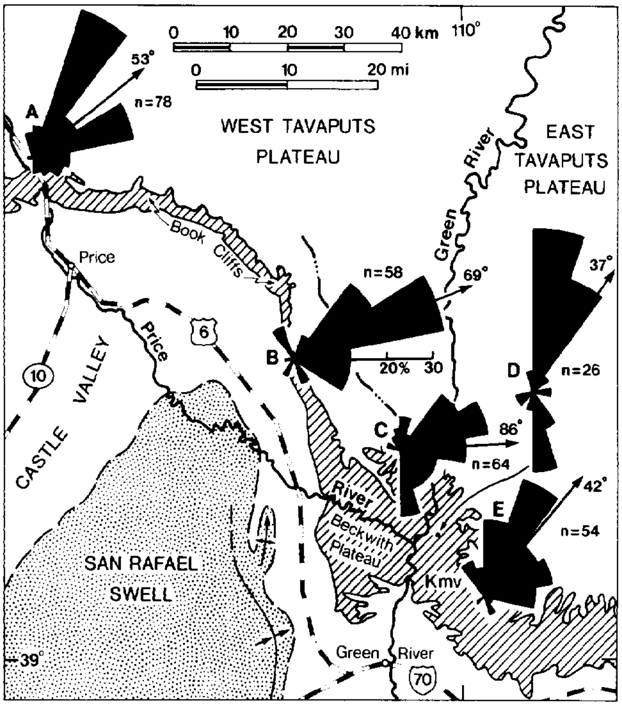

Figure 6—Paleocurrent data from Bluecastle Tongue of Castlegate Sandstone. All measurements from axes of trough cross bedding. Localities: A. Price Canyon; B. Horse Canyon; C. Range Creek; D. Green River; E. Tusher Canyon.

to formation rank by Fisher et al. (1960), although it was previously designated as a formation by Cobban and Reeside (1952). In the study area it is restricted to sections east of the San Rafael Swell, where it lies on the variably bleached and oxidized upper surface of the Bluecastle Tongue of the Castlegate Sandstone. The nature of the surface and an abrupt change to lithic sandstone (discussed later) indicate that the contact may be a disconformity, although palynomorph data suggest that little time is represented by the contact (Fouch et al., 1983). The unit is 290 m (951 ft) thick in Tusher Canyon, thins westward to 90 m (295 ft) at Horse Canyon, and is at most 40 m (131 ft) thick at Soldier Canyon, where it is directly overlain by the North Horn Formation.

The Farrer Formation as used here includes that portion of the post-Bluecastle section rich in siltstone and mudstone, although sandstone makes up 40–50% of the section. The lower part of the Price River Formation in Price Canyon, which is the western equivalent of the Farrer Formation, contains much more sandstone, up to 75%. Correlatives of the Farrer Formation thus appear to coarsen westward toward the thrust belt, but precise time equivalence is difficult to confidently establish between the eastern and western sections.

The Farrer consists of interbedded sandstone and thick siltstone and silty sandstone beds. The sandstone beds are 5–18 m (16–59 ft) thick and broadly lenticular with scoured bases. Grain size and size of primary structures diminish upward within the greenish- to brownish-gray beds of very fine to medium-grained micaceous sandstone. Mudstone chips are common in scour-and-fill structures and are dispersed on foresets of trough cross beds low in the sandstone beds. Trough cross beds occur above the scoured bases in the lower 1–7 m (2–23 ft) of each sandstone unit and are common throughout the sandstone beds. Trough cross beds are associated with convolute lamination and planar cross beds in the middle parts of the beds and give way upward to horizontal and ripple lamination near sandstone bed tops.

Siltstone deposits gradationally overlie the sandstone beds. In general, the siltstone beds are light greenish gray and interbedded with poorly exposed dark brown shale and silty shale. Sparse interbeds of lenticular to tabular very fine to fine-grained silty sandstone 10–250 cm (4–100 in.) thick occur in the siltstone sequences. The sandstone beds both coarsen and fine upward in different examples and contain ripple lamination as well as planar and trough cross beds. Mudstone chips are common in the silty sandstone beds; bed tops are commonly burrowed and rooted and contain abundant leaf impressions.

The fining-upward sandstone sequences and thick siltstone sequences of the Farrer Formation are characteristic of meandering river deposits. The sandstones were most likely deposited in channel complexes or point bars, while the siltstone sequences represent floodplain deposits. The thin silty sandstone beds in the siltstone facies are interpreted as crevasse splay deposits. Thicknesses of the sandstone units suggest that Farrer rivers were large, with bankfull channel depths of as much as 18 m (59 ft). Paleocurrent measurements taken from many horizons indicate consistent sediment transport to the east and northeast (Figure 7).

Tuscher Formation

The sandstone-dominated sequence above the Farrer Formation and below the North Horn Formation was named the Tuscher Formation (Fisher, 1936) for exposures in a canyon east of the Green River. The canyon's name is now spelled Tusher on topographic quadrangle maps. The Tuscher Formation was assigned a Tertiary(?) age by Fisher (1936) and a Late Cretaceous age by Cobban and Reeside (1952) and Fisher et al. (1960). Keighin and Fouch (1981) discussed the confusion that exists over the actual stratigraphic limits of the Tuscher Formation and considered the lower Tuscher to be of Late Cretaceous age and a pebbly zone within the upper 50 m (164 ft) of the unit to be of Paleocene age. Pollen collected recently from two localities in the uppermost 25 m of the unit at Range Creek indicate a latest Campanian age for the top of the Tuscher Formation there (Fouch et al., 1983).

The Tuscher Formation is 280 m (919 ft) thick at Tusher Canyon, 183 m (600 ft) thick on the Green River, 109 m (358 ft) thick at Range Creek, and absent in more western localities, although the "pebbly beds" described below are believed to be equivalent to the upper pebbly part of the unit. The lower gradational contact with the Farrer Formation was picked in this study where the sandstone content of the section exceeds 50%. Some thickness variation within the study area may be due to the gradational nature of the contact.

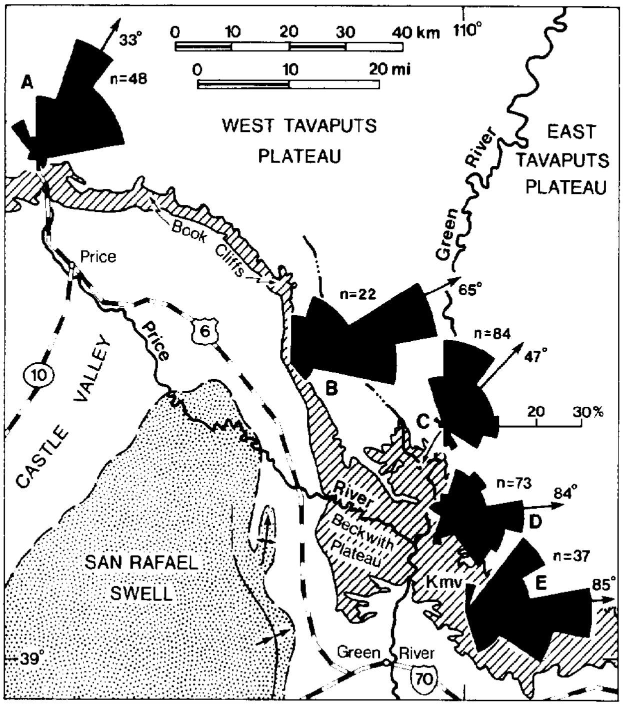

Figure 7—Paleocurrent data from Farrer Formation (east of San Rafael Swell) and lower 90 m of Price River Formation (Price Canyon). All measurements from axes of trough cross bedding. Localities: A. Price Canyon; B. Horse Canyon; C. Range Creek; D. Green River; E. Tusher Canyon. Ruled area indicates Mesaverde Group (Kmv).

The Tuscher Formation consists of tan-weathering sandstone sheets 7-15 m (23-50 ft) thick interbedded with siltstone and shale intervals 5-25 m (16-83 ft) thick. Within the lower part of the unit, the sheets typically consist of a lower medium- to fine-grained sandstone interval 5-10 m (16-33 ft) thick that fines upward to interbeds of very fine to fine-grained sandstone and siltstone that have depositional dips of as high as 20°. The inclined sandstone and siltstone beds were observed to terminate laterally in lenticular deposits of laminated shale and siltstone. The inclined sandstone beds are dominantly ripple laminated and range from 5 to 30 (2-12 in.) cm thick; interbedded siltstone is 5 to 10 cm (2-4 in.) thick. Bed sets (and laterally equivalent shale and siltstone lenses) reach 4 m (13 ft) thick. In some cases, the sandstone sheets grade upward into siltstone and shale intervals; in other cases, trough cross-bedded sandstone of the overlying sheet rests directly on any lithofacies in the lower sheet. The base of each sheet is a sharp erosional contact, and mudstone clasts are common in trough cross beds of the lower 2-5 m (7-16 ft) of each sheet. Trough cross beds are the most common primary structure. The sandstone is poorly sorted, with grain size ranging from fine to coarse.

Gray siltstone and claystone compose less than 50% of the unit. Broadly lenticular, very fine grained sandstone beds as much as 0.5 m (1.6 ft) thick occur within the siltstone intervals. The sandstone beds contain bone fragments, rootlet holes, and more rarely, the trace fossil *Palaeophycus*, possibly formed by insect burrowing (Stanley and Fagerstrom, 1974; Ratcliff and Fagerstrom, 1980). Transitions from sandstone to siltstone are abrupt.

At Range Creek, the Green River, and Tusher Canyon, the Tuscher Formation coarsens upward into pebbly sandstone. Pebbles initially appear in the section dispersed in trough cross bedding and increase in abundance up-section. The upper 50 m (164 ft) of the section on the Green River consists of pebbly coarse sandstone with low-angle cross beds, often in lenticular scour-and-fill structures as much as 1 m (3 ft) thick. The pebbles are rounded, a maximum of 2.5 cm (1 in.) in diameter, and consist of gray and tan banded chert, black chert, very fine grained white quartz arenite, gray quartzite, pink monocrystalline quartz, pale green felsite(?), and white mudstone.

The sheetlike sandstone bodies within the lower part of the Tuscher Formation were most likely deposited by meandering rivers, as evidenced by the inclined lateral accretion beds associated with lenticular abandoned channel siltstone and shale, the fining-upward grain sizes, and the silty floodplain deposits that separate the sheets. The change upward to coarse-grained pebbly sandstones with low-angle cross beds and pebble lenses records a shift to deposition by pebbly braided streams. Paleocurrent measurements in the Tuscher Formation (Figure 8 C, D, and E) indicate northeastward transport in the lower part of the unit. Paleocurrents in the upper pebbly part of the unit are also northeasterly, with a north–northwest mean at the Range Creek locality (Figure 9). Cross bed measurements in the upper Price River Formation at Price Canyon and Joes Valley likewise indicate northeast-directed transport (Figure 8 A and B).

Pebbly Beds

West of Range Creek, the Tuscher Formation pinches out beneath Tertiary sedimentary rocks. At Little Park, only 120 m (394 ft) of Farrer rocks are preserved beneath the North Horn Formation of late Paleocene age. Local mapping of the Little Park locality shows that the North Horn Formation overlies the Farrer Formation with a few degrees of angular discordance (Figure 10). The angular relationship and the absence of Tuscher beds east of the Range Creek measured section are used to infer the regional truncation above the Mesaverde Group (Figure 11).

Broad, white-weathering lenses of coarse granule and small pebble sandstone occur between the Farrer Formation and the North Horn Formation. This white pebbly sandstone horizon occurs discontinuously along strike and is also present in the Horse Canyon section and at Whitmore Canyon. The basal contact is sharp and erosional. The sandstone ranges from 18 m (59 ft) thick at Little Park to 6 m (20 ft) thick at Horse Canyon and appears to be concordant with the underlying Farrer beds. It consists of poorly sorted, fine to coarse-grained, quartzose to sublithic sandstone in lenticular beds with discontinuous accumulations of 4-5 mm (0.16-0.2 in.) pebbles and angular granules above erosional bedding contacts. Pebble lithologies are dominated by light gray, very fine grained quartz sandstone with subordinate dark to light gray chert, monocrystalline white and pink quartz, and white mudstone. Rounded clasts, 5-10 cm (2-4 in.) in diameter, of fine-

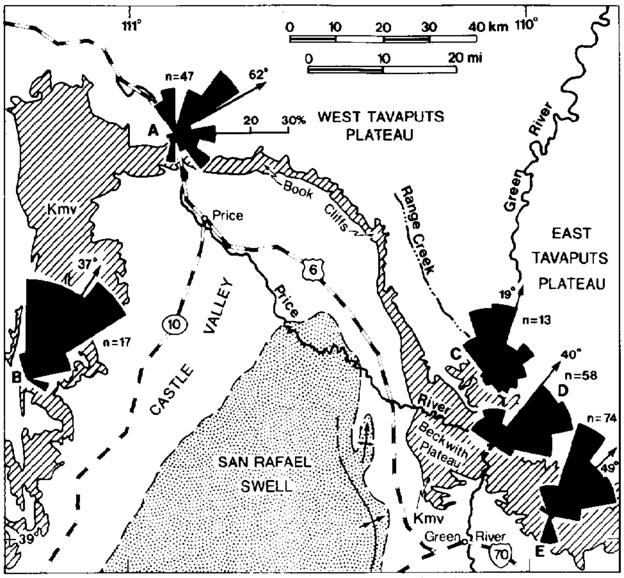

Figure 8—Paleocurrent data for upper part of Mesaverde Group. Measurements from trough cross-bedding axes of the Upper Price River Formation at Price Canyon (A) and Joes Valley (B), and the nonpebbly part of the Tuscher Formation at Range Creek (C), the Green River (D), and Tusher Canyon (E). Extent of Mesaverde Group outcrops is indicated by diagonal ruled pattern.

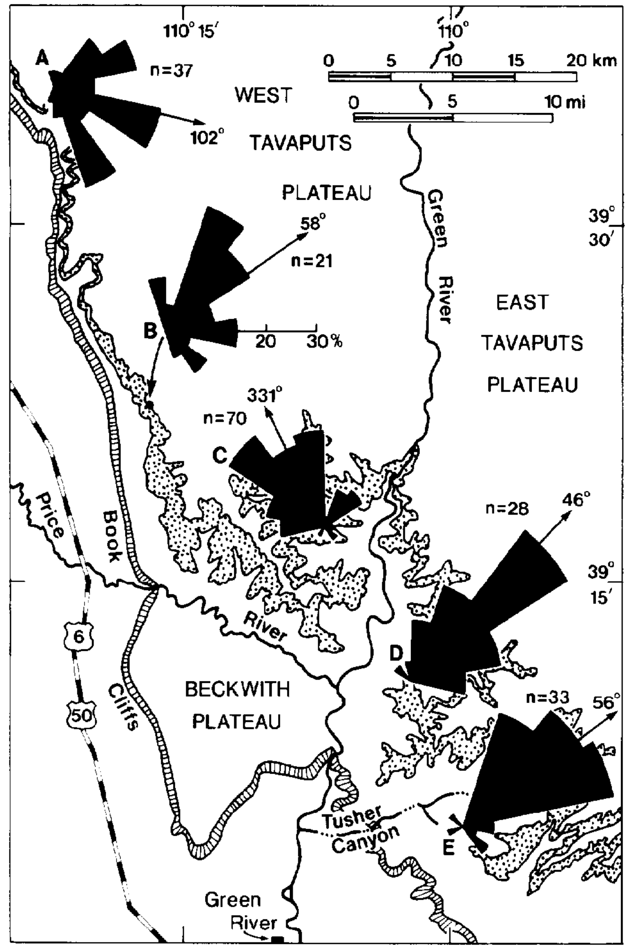

Figure 9—Paleocurrent data from "pebbly beds" at Whitmore Canyon (A) and Little Park (B), and pebbly part of Tuscher Formation at Range Creek (C), Green River (D), and Tusher Canyon (E). All measurements on axes of trough cross bedding. Distribution of Mesaverde Group is indicated by stipple. Ruled pattern indicates location of Book Cliffs.

grained quartzose sandstone are common in some trough lags. Trough cross beds and contorted lamination are the most common structures in the unit.

Measurements on trough cross bed axes in the discontinuous white sandstone indicate easterly to northeasterly paleocurrents (Figures 9 and 10). Pebble size and lithology in westernmost exposures of upper Tuscher beds are more similar to those of pebbles in the pebbly beds than to those in the upper Tuscher Formation at Tusher Canyon and elsewhere.

Because of their stratigraphic position and lithologic characteristics, the pebbly beds are believed to have been deposited at the same time as the uppermost part of the Tuscher Formation, and they thus probably represent east-flowing tributaries of the main northeast-flowing Tuscher river system. Because they are not dated, the possibility must be considered that they are actually reworked Cretaceous rocks deposited during the Tertiary prior to onlap by the North Horn Formation. Geologic relationships noted previously, however, indicate structural concordance with the Campanian section and stratigraphic equivalence with some part of the Tuscher Formation. In addition, a potential stratigraphic counterpart intermediate in age between Tuscher and North Horn beds remains unrecognized or is absent within the study area and for 20 km (12 mi) to the east, in the vicinity of Thompson Canyon, where conglomeratic sandstone beds of Paleocene age are present (T. D. Fouch, personal communication, 1983).

POST-CAMPANIAN OVERLAP STRATA (NORTH HORN FORMATION)

The North Horn Formation overlies the Price River Formation west of the San Rafael Swell and the Tuscher Formation east of the swell. The base of the unit is broadly diachronous, as discussed earlier, and varies in both lithic type and thickness. In the central Wasatch Plateau, the type North Horn Formation consists of 500 m (1640 ft) of variegated fluvial and lacustrine rocks deposited during Maestrichtian and Paleocene time, which is overlain by the Flagstaff Limestone (Spieker, 1946). At Joes Valley 10 km (6 mi) north of the type locality, tan fluvial sandstone of the North Horn overlies bleached feldspathic sandstone of the Price River Formation on a sharp contact marked by a conglomerate lag and grades upward into a section dominated by siltstone.

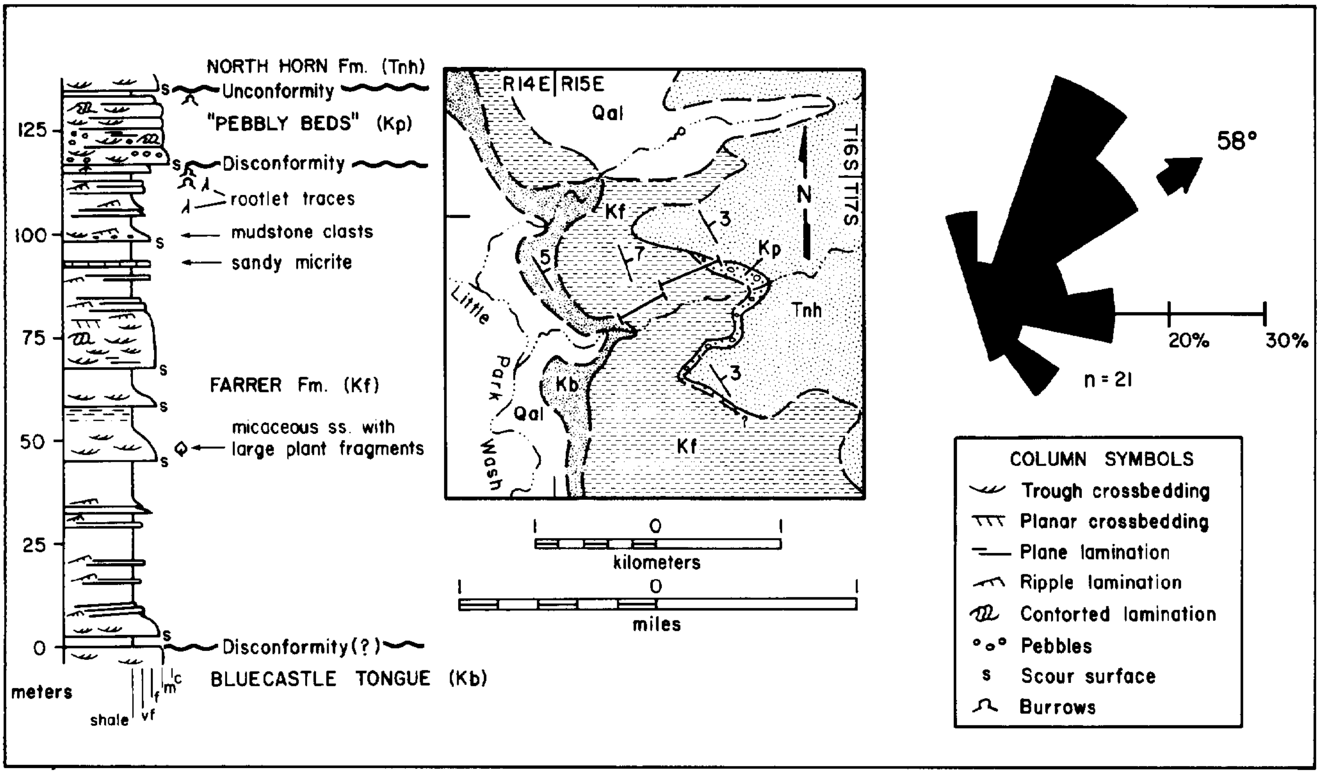

Figure 10—Stratigraphic and structural relationships of Farrer Formation, "pebbly beds," and North Horn Formation at Little Park locality, showing overlap of Tertiary strata. Paleocurrents measured in pebbly beds indicate northeastward to eastward flow on flank of San Rafael Swell, represented by dips in Cretaceous rocks, and contrast with strong northeastward to northward current directions nearby at Range Creek (Figure 9). Location of measured section is shown by line segments on map.

Thin-bedded, dark gray calcareous siltstone and mudstone of lacustrine origin form the basal 65 m (213 ft) of the North Horn Formation in Price Canyon (Lawton, 1983). The gray beds are overlain by 220 m (721 ft) of interbedded sandstone and siltstone. The sandstone and siltstone beds form upward-fining cycles that average 10 m (33 ft) in thickness. The sandstone beds have sharp bases; detrital micrite clasts and mudstone chips are common in the lower parts of the beds, which consist of fine- to medium-grained sandstone. Trough cross beds near the base decrease in amplitude upward and grade into ripple lamination. Very fine grained sandstone beds, 10–50 cm (4–20 in.) thick and interbedded with thin siltstone beds, cap the sandstone intervals and grade into thick siltstone intervals. In the upper part of the section, the fining-upward cycles are interrupted by intervals of very fine to fine-grained, rippled, and burrowed sandstone 5 m (16 ft) thick.

The gray calcareous siltstone beds in the lower part of the North Horn Formation in Price Canyon were deposited in a lacustrine environment. Lake sedimentation was succeeded by meandering stream deposition that characterized the North Horn Formation in Paleocene time (Fouch et al., 1983). Bioturbated and rippled horizons near the top of the unit represent lake margin sandstones deposited late in Paleocene time prior to deposition of the Flagstaff Limestone.

East of the San Rafael Swell, in contrast, no thick calcareous siltstone or shale is present at the base of the North Horn section. North Horn-type clastics grade rapidly upward into and interfinger with Flagstaff carbonate strata, making the units difficult to differentiate. However, an interval of sandstone and shale from 15 to 40 m (49–131 ft) thick occurs beneath limestone-dominated lithologies in the areas studied. Sandstone beds are lenticular, as much as 10 m (33 ft) thick, and fine upward from medium- to fine-grained sandstone. The sandstone and shale were probably deposited in a meandering stream environment.

SANDSTONE COMPOSITION

A change from quartz-rich to lithic-rich sandstone compositions occurs within the Mesaverde Group above the Bluecastle Tongue of the Castlegate Sandstone. This change serves as a basis for dividing the nonmarine strata of the upper part of the Mesaverde Group into two compositional subdivisions, a quartzose petrofacies and a lithic petrofacies. The quartzose petrofacies includes a stratigraphic interval dominated by sandstones composed of greater than 80% total framework quartz. This interval includes the Castlegate Sandstone in Price Canyon and the Castlegate Sandstone, the Neslen Formation, and the Bluecastle Tongue of the Castlegate Sandstone in eastern exposures. The lithic petrofacies comprises a stratigraphic interval having sandstones generally containing less than 80% framework quartz. The lithic petrofacies includes the Price River

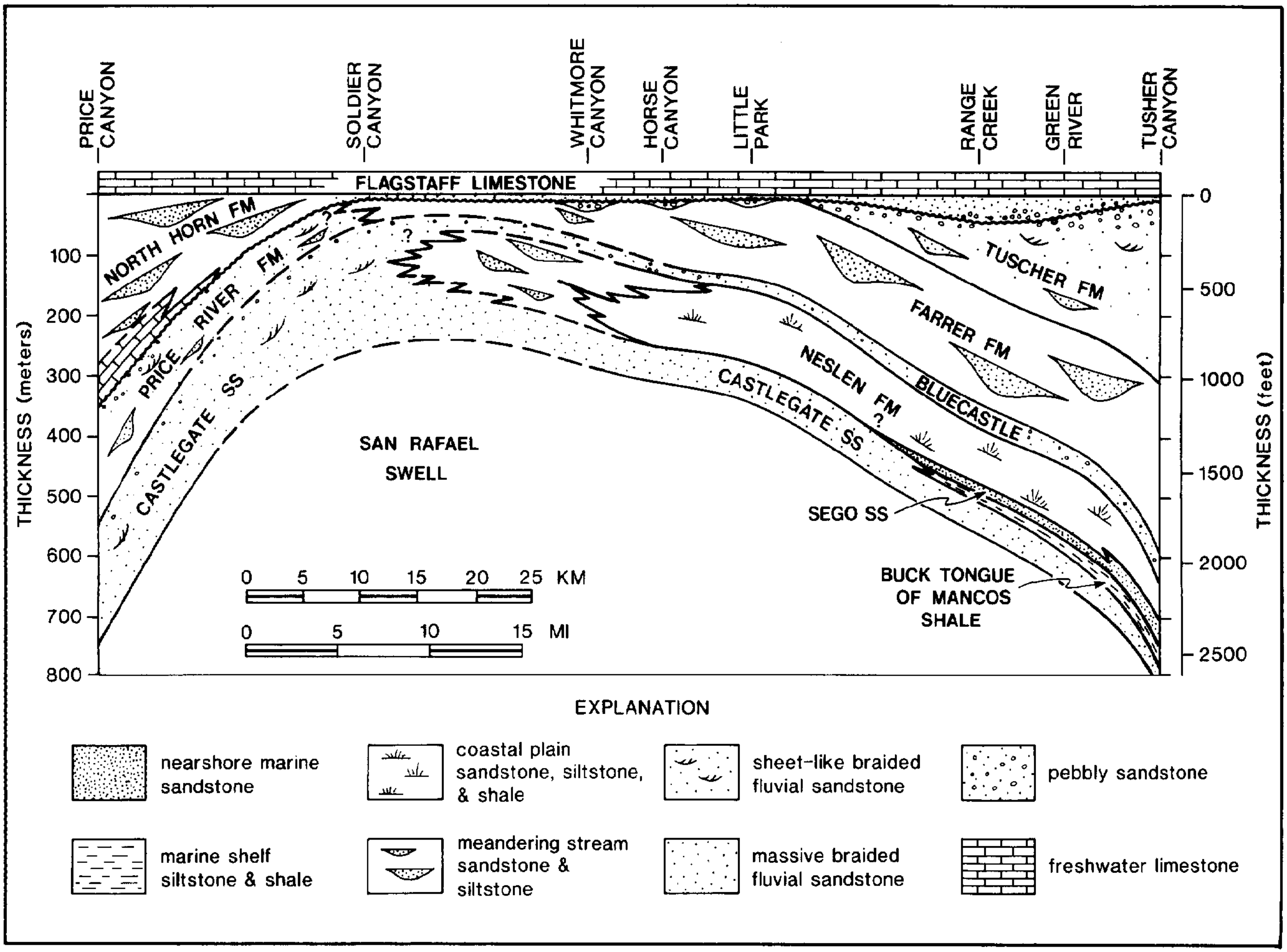

Figure 11—Stratigraphic relation of the upper part of the Mesaverde Group from west to east across the San Rafael Swell. Section thicknesses at Soldier and Whitmore canyons are from Fisher et al. (1960).

Formation in Price Canyon and the Farrer and Tuscher formations near the Green River. At the top of the Mesaverde section, a return to quartzose compositions occurs in both the Price River and Tuscher formations. A summary of mean modal compositions of Mesaverde Group sandstones is given in Table 1.

Although the petrologic shift occurs regionally at the same stratigraphic position, the lithic grain population present in the Price River Formation contrasts with that of the Farrer and Tuscher formations. Sandstone east of the San Rafael Swell is feldspathic litharenite (following the usage of McBride, 1963), with a maximum abundance of mica and volcanic lithic fragments occurring low in the section. Sedimentary lithic fragments increase in abundance up-section in the Tuscher Formation. Sandstone west of the swell is litharenite and sublitharenite with only small amounts of potassium feldspar. The contrast in grain types is shown in Figure 12 by the use of a triangular plot (Graham et al., 1976) of the relative abundances of polycrystalline quartz including chert (Qp), sedimentary lithic fragments (Ls), and volcanic lithic fragments (Lv). To ensure statistical significance of the lithic grain fraction plotted in Figure 12, only sandstone samples containing a framework lithic population of greater than 25% are plotted. The plot indicates that the lithic grain population of sandstones in the Price River Formation is dominated by sedimentary rock fragments, whereas a variable but significant fraction of the lithic population of the Farrer and Tuscher formations consists of volcanic grain types. Lithic fragments are again uncommon in quartz-rich strata of the uppermost part of both the Price River and Tuscher formations.

Compositional trends are apparent within the petrographic subsuites. The percentage of total quartz in sandstones of the Price River Formation varies along a linear trend at a nearly constant mean $L/(L + F)$ ratio of 0.80, where L is lithic fragments and F is feldspar (calculated from the mean modal composition in Table 1) (see Figure 2), with more quartzose samples occurring in the upper 90 m (295 ft) of the section. A similar linear trend in lithic sandstone of the Black Warrior and Ouachita basins has been explained as a result of addition of quartz grains from outside sources (multiple source dilution) and variable compositional maturity of the sandstones (Graham et al., 1976). Both processes may have operated in the Utah foreland, but the work of Pollack (1961) on compositional

Table 1—Mean modal compositions of Mesaverde Group sandstones and definition of grain parameters.[a, b]

Unit	*n*	Q	F	L	Qm	Lt	K	P	Qp	Ls	Lv	Detrital CO_3
Castlegate Sandstone	12	89.3 (12.7)	0.9 (1.2)	9.8 (13.0)	84.0 (11.8)	14.2 (12.3)	0.8 (1.1)	0.1 (0.2)	4.4 (3.4)	9.4 (12.8)	0.2 (0.6)	7.6 (12.9)
Neslen Formation	1	77.0	5.0	18.1	66.8	28.3	3.0	2.0	10.2	10.0	2.0	3.9
Bluecastle Tongue	8	96.8 (3.7)	0.5 (0.7)	2.6 (3.3)	92.7 (6.7)	6.7 (6.4)	0.1 (0.2)	0.3 (0.6)	2.0 (3.0)	2.6 (3.3)	0	2.0 (3.0)
Price River Formation	21	75.5 (17.2)	5.1 (3.8)	19.4 (13.7)	66.4 (18.9)	28.5 (15.4)	4.7 (3.9)	0.4 (0.6)	9.1 (4.0)	12.6 (8.2)	3.4 (5.1)	3.5 (4.3)
Farrer Formation	10	51.3 (8.0)	18.0 (4.4)	30.7 (10.4)	37.2 (7.0)	44.8 (9.1)	9.1 (2.7)	8.9 (2.8)	14.1 (4.2)	14.5 (4.3)	13.3 (9.7)	5.0 (3.7)
Tuscher Formation	13	64.1 (11.7)	15.4 (5.5)	20.5 (7.2)	51.5 (10.2)	33.1 (7.6)	10.1 (3.6)	5.3 (3.6)	12.6 (5.2)	10.5 (4.3)	7.2 (6.1)	1.2 (2.3)

[a]Numbers in parentheses are standard deviations.
[b]Q + F + L = 100%; Qm + F + Lt = 100%. Q is total framework quartz (Q = Qm + Qp), where Qm is monocrystalline quartz, including uniform extinction and undulose extinction; and Qp is polycrystalline quartz, including chert, polycrystalline quartz of sedimentary, igneous, and metamorphic origin, and aggregate quartz of indeterminate origin. F is total framework feldspar (F = K + P), where K is potassium feldspar and P is plagioclase feldspar. L is framework lithic fragments (for QFL plot; L = Ls + Lv + Lo), where Ls is sedimentary lithic fragments, including argillite (shale), very fine grained feldspathic sandstone, and detrital carbonate; Lv is volcanic (hypabyssal lithic fragments), including microlitic volcanic rock fragments, hypabyssal volcanic rock fragments, and felsite; and Lo is lithic fragments of other origin, including plutonic rock fragments, polycrystalline quartz + white mica, and polycrystalline white mica. Lt is total framework lithic fragments (Lt = L + Qp).

trends in sand of the South Canadian River suggests that transport distances significantly greater than the distance between the Wasatch Plateau and the Green River would have been required to alter modal compositions. Thus, multiple sources may have been a more important factor in determining petrographic variability.

A petrographic trend is also indicated for the lithic component of Farrer and Tuscher sandstones, in which the Lv content appears to vary along a linear trend at a nearly constant mean Qp/(Qp + Ls) ratio of 0.52 on the QpLvLs plot (calculated from mean modal compositions for the combined Farrer and Tuscher formations in Table 1) (see Figure 12). The Lv trend suggests either (1) selective disappearance of volcanic lithic fragments during transport of an originally volcanic-rich clastic suite derived from a source outside the thrust belt, or (2) dilution of an originally volcanic-rich clastic suite by addition of Ls and Qp components in a nearly constant ratio, possibly determined by the source area. In either case, it is clear that Price River fluvial systems did not contribute the observed Lv component. Moreover, paleocurrent data show that neither the Farrer nor the Tuscher Formation lies in a downcurrent direction from Price River sites studied, although more southern locations in the Wasatch Plateau may have contributed detritus.

TECTONIC AND PALEOGEOGRAPHIC EVOLUTION OF THE FORELAND REGION

The observed stratigraphic relationships and trends in depositional facies, dispersal directions, and sandstone compositions were a response to changing tectonic conditions in Late Cretaceous to early Tertiary time in the Utah foreland. Late in Mesaverde time, primary deformation and uplift shifted from the thrust belt to sites previously characterized by subsidence and clastic deposition within the foreland basin. The following discussion is an interpretation of tectonic and paleogeographic events for Campanian, Maestrichtian, and much of Paleocene time.

Middle to Late Campanian Time

During the time bracketed by the range fossils *Baculites asperiformis* and *Exiteloceras jennyi* (74–79 m.y.), the uplifted terrane of the thrust belt was the primary source of quartzose clastic detritus that was shed eastward and southeastward into the subsiding foreland basin. The lower cliff-forming part of the Castlegate Sandstone has long been interpreted as a depositional response to an episode of major uplift in the thrust belt (Spieker, 1946, 1949; Van De Graaff, 1972). Fouch et al. (1983) suggested that uplift coincided with movement on the Meade–Crawford thrust system in northern Utah and Wyoming. It may represent early movement on the Charleston–Nebo thrust and uplift of Precambrian quartzite in thrust sheets above the Pavant thrust farther south (Lawton, 1983). The Castlegate Sandstone records fluvial deposition on a sandy coastal plain that extended for at least 130 km (80 mi) (the present exposed length of the Castlegate Sandstone on the Wasatch Plateau) parallel to the thrust front. Dominantly braided rivers flowed directly away from the linear uplifted front to a shoreline located near the Colorado–Utah border (Van De Graaff, 1972).

Decreased sediment influx or more rapid subsidence in the basin following deposition of the lower part of the Castlegate resulted in a return of marine conditions to the

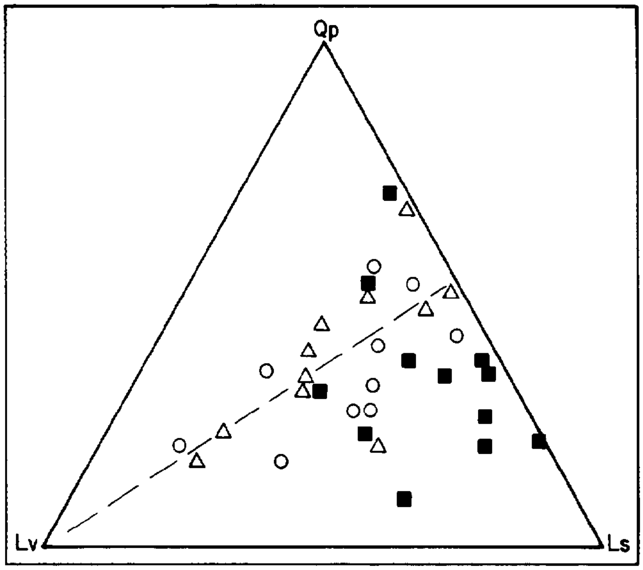

Figure 12—Triangular QpLsLv compositional plot of sandstones of Price River, Farrer, and Tuscher formations. Qp, polycrystalline quartz, including chert; Ls, sedimentary lithic grains, including detrital carbonate; Lv, volcanic lithic grains. Dashed line is Qp/(Qp + Ls) = 0.52, calculated from mean modal values in Table 1.

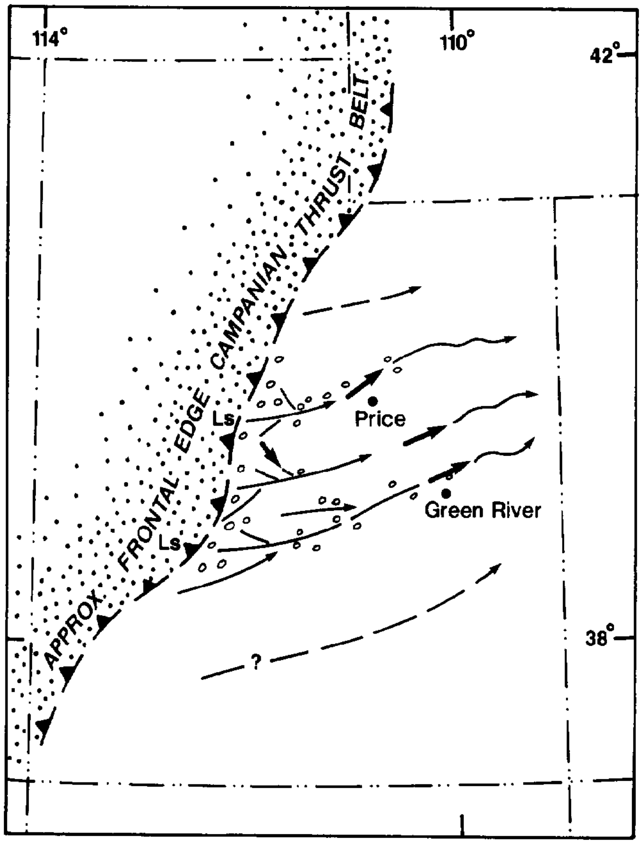

Figure 13—Inferred coastal plain fluvial system developed during deposition of the Bluecastle Tongue of Castlegate Sandstone. Bold arrows show paleocurrent locations of Figure 6, except for arrow nearest thrust front, taken from data for uppermost Sixmile Canyon Formation (Indianola Group) (Lawton, 1982). Symbol within source area indicates derivative grain type: Ls, sedimentary lithic fragments.

Green River area. Time-equivalent rocks of the middle part of the Castlegate Sandstone in Price Canyon were deposited by meandering rivers.

The Bluecastle Tongue of the Castlegate Sandstone forms a clastic blanket continuous throughout the study area, and constitutes the last major pulse of coarse sediment from the thrust belt that can be traced petrologically from the northern Wasatch Plateau into the Green River area (Figure 13). Post-Bluecastle rivers transported detritus northeastward from the vicinity of Price Canyon. The Bluecastle Tongue was deposited by braided rivers that increased in sinuosity eastward away from the source area. Like the lower part of the Castlegate Sandstone, the Bluecastle Tongue was deposited on a sandy coastal plain, but stream flow was obliquely away from the thrust belt. The Bluecastle Tongue is thinner than the lower part of the Castlegate Sandstone, but composed of coarser sandstone, factors that suggest derivation from a discrete uplift event in the thrust belt and a source more proximal than the source of the Castlegate Sandstone. This uplift is postulated by Fouch et al. (1983) to be coincident with movement on the Absaroka thrust in Wyoming and Utah north of the Uinta Mountains. Folding and ramping of the Charleston–Nebo structure at this time probably exposed quartzite cobble conglomerates of the Upper Cretaceous Indianola Group, which contributed to the coarse quartzose nature of the Bluecastle.

Late Late Campanian Time

Evidence exists in the sedimentary record for modification and eventual termination of foreland basin deposition between the zones of *Exiteloceras jennyi* and *Baculites cuneatus* (73–74 m.y.). Thrust belt deformation west of the Price Canyon area continued, probably as late uplift of the Charleston–Nebo structure and folding above more eastern blind thrusts (Lawton, 1985). Paleocurrent data from the Price River and Farrer formations indicate that the major fluvial systems were longitudinal or subparallel to the thrust front. Northeast-flowing meandering rivers deposited the Price River Formation, which consists of sandstone rich in sedimentary lithic fragments from the thrust belt. Coeval meandering rivers that deposited the Farrer Formation also flowed northeastward, but sandstone compositions indicate that these rivers tapped volcanic sources lying far to the southwest (Figure 14). The Farrer rivers thus probably constituted a long trunk system. Tributary streams draining the thrust belt transported sedimentary lithic grains and monocrystalline quartz grains to the trunk system. The amount of detrital material derived from the thrust belt probably varied as tributary systems evolved and resulted in the variable percentage of volcanic lithic grains observed on the QpLsLv plot (Figure 12). Although the fluvial pattern apparently consisted of a trunk–tributary system oriented subparallel to the thrust belt, a north to northwest-trending shoreline lay approximately 160 km (100 mi) to the east in present-day Colorado and southwestern Wyoming (Kiteley, 1983; Molenaar, 1983); thus, the system probably retained some characteristics of a coastal plain as well. The fluvial pattern developed during deposition of the Farrer

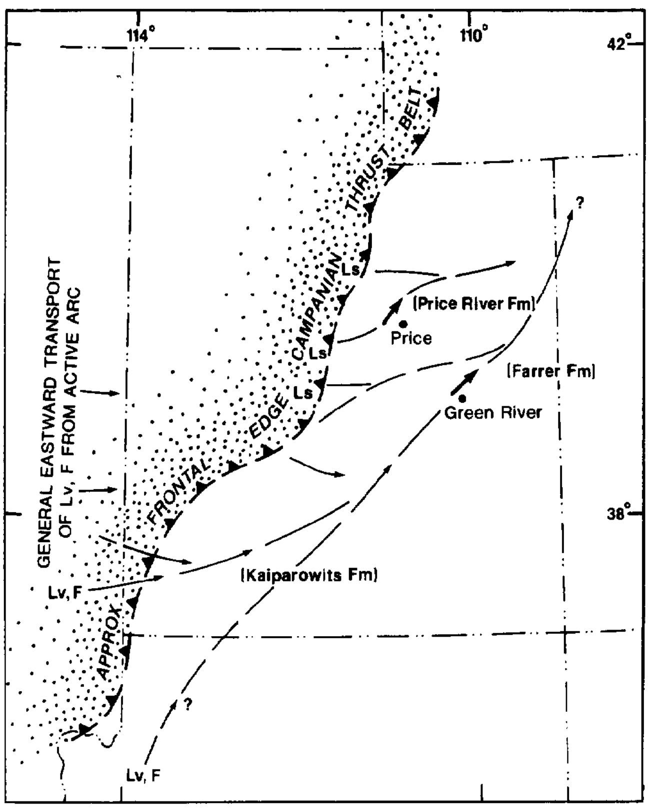

Figure 14—Inferred trunk-tributary fluvial system and source terranes during deposition of Farrer and lower Tuscher formations and their equivalents. Bold arrows show paleocurrent localities of Figures 7 and 8. Symbols within source areas indicate derivative grain types: Ls, sedimentary lithic fragments; Lv, volcanic lithic fragments; F, feldspar.

Formation persisted during deposition of most of the Tuscher Formation.

Time-equivalent units at the top of the Cretaceous section in the Kaiparowits Plateau region of southwestern Utah are richer in feldspar and volcanic fragments than the Farrer and Tuscher formations (Bowers, 1972). These units, the Kaiparowits and overlying Canaan Peak formations, are inferred to have been deposited by upstream reaches of the Farrer and Tuscher fluvial trunk system more proximal to the volcanic source rocks that probably lay beyond the thrust belt (Figure 14).

Depositional changes in the uppermost part of the Mesaverde section indicate a change in the trunk-tributary fluvial system. Braided fluvial deposition in the uppermost part of the Price River Formation of Price Canyon probably records the final stages of folding in the easternmost thrust belt. In the east, braided rivers that deposited the upper part of the Tuscher Formation succeeded the earlier meandering streams. As mentioned previously, sandstone of the uppermost part of the Tuscher Formation is quartzose. The decrease and disappearance up-section of volcanic lithic grains within the upper part of the Tuscher Formation is interpreted to signal progressive isolation of the Tuscher river systems from the volcanic terrane to the southwest. Mesozoic strata of the San Rafael Swell, Circle Cliffs uplift, and the Monument upwarp probably began to provide a sedimentary source terrane for the uppermost Tuscher sandstone (Figure 15). With the initiation of the thick-skinned uplifts, the fluvial systems were altered, becoming intermontane trunk-tributary systems. The intraformational nature of the quartz arenite and sublitharenite clasts found in the pebbly beds indicates recycling of foreland basin sandstone from the San Rafael Swell. Moreover, a contrast in pebble lithology, size, and shape between the upper part of Tuscher Formation and the pebbly beds suggests different sources for the pebble populations. Pebbles of the pebbly beds were most likely recycled from uplifted pebbly strata of the Price River Formation.

On the basis of this study, the favored interpretation for the age of the pebbly beds, and hence, uplift of the San Rafael Swell, is latest Campanian. The interpretation requires that the synorogenic pebbly beds are equivalent to the uppermost pebbly strata of the Tuscher Formation. This inference is supported by the stratigraphic equivalence of the two units beneath the pre-North Horn unconformity. Onlap of basal North Horn strata across truncated older beds indicates that structural relief on the swell was attained prior to North Horn deposition (Figure 10).

Growth of the San Rafael Swell and development of intermontane fluvial systems clearly occurred between latest Campanian and late Paleocene time. The Campanian age interpreted here is consistent with stratigraphic and sedimentologic relationships in the study area, particularly in the absence of an intermediate Maestrichtian or lower Paleocene unit between the Tuscher and North Horn formations. Because such a unit appears to be present east of the study area, as mentioned previously, careful mapping of the unconformity below the North Horn and direct dating of the pebbly beds may be necessary to unequivocally resolve the age question.

Post-Campanian Time

Campanian rocks are succeeded by an unconformity everywhere in the study area and probably throughout the eastern Utah and western Colorado regions (Hansley and Johnson, 1980). Sedimentation resumed in the study area in the vicinity of the Wasatch Plateau in Maestrichtian time at about 70 m.y. ago (Spieker, 1946; Fouch et al., 1983). Deposition first occurred in meandering stream and lacustrine environments as drainage ponded in the structural depression between the thrust belt and the San Rafael Swell. East-directed meandering fluvial deposition resumed and continued into Paleocene time. Sandstone compositions and the stratigraphic position of the lower Tertiary fluvial strata indicate equivalence to the quartzite- and carbonate-clast conglomerates that form a basal facies of the North Horn Formation to the west and onlap deformed rocks of the thrust belt (Merrill, 1972; Pinnell, 1972; Young, 1976; Weiss, 1982). The coarse-grained strata may record final isostatic uplift of the thrust terrane as tectonically thickened crust was thinned by erosion. The deposition that began in Maestrichtian time expanded westward from the Wasatch Plateau and onlapped the frontal deformed belt of the thrust terrane by late Paleocene time (Figure 16) (Stanley and Collinson, 1979; Fouch et al., 1982). The depositional relationships of the overlap sequence thus indicate that

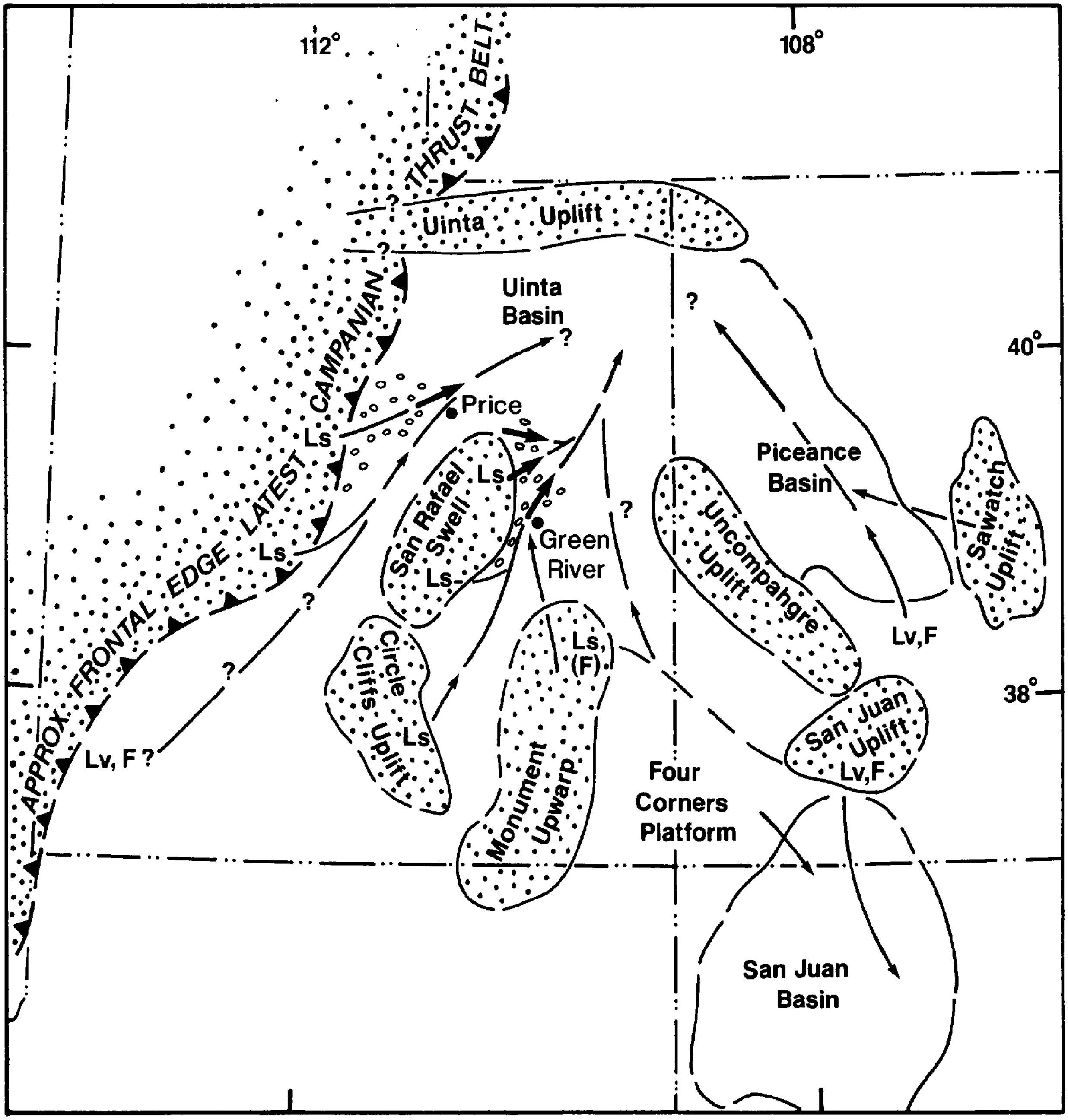

Figure 15—Inferred intermontane trunk-tributary fluvial system and extant source terranes during deposition of upper part of Price River Formation, pebbly Tuscher Formation, pebbly beds, and equivalents. Equivalents include the Canaan Peak Formation in southwest Utah (Bowers, 1972), the Ohio Creek Member of the Hunter Canyon and Mesaverde formations in the Piceance Creek basin (Johnson and May, 1980), and the Fruitland and Kirtland formations of the San Juan basin. Bold arrows show relevant paleocurrent localities of Figures 8 and 9. Symbols within source areas indicate derivative grain types: Ls, sedimentary lithic fragments; Lv, volcanic lithic fragments; F, feldspar. Inferred source areas for Piceance Creek basin are from Hansley and Johnson (1980); for the San Juan basin from M. A. Klute (personal communication, 1982). Structural elements of Colorado Plateau and Rocky Mountain regions are after Kelley (1955).

thrusting was unequivocally complete by Paleocene time, but probably terminated during the Maestrichtian. North Horn rocks also onlapped the arch of the San Rafael Swell farther east as the structural basin filled with sediment. Onlap of the swell was complete by latest Paleocene time (Fouch et al., 1982).

CONCLUSIONS

Patterns of sedimentation and sandstone compositions in central Utah record an eastward expansion of tectonism from the thrust belt into the foreland region during late Campanian time. Foreland basin sedimentation was

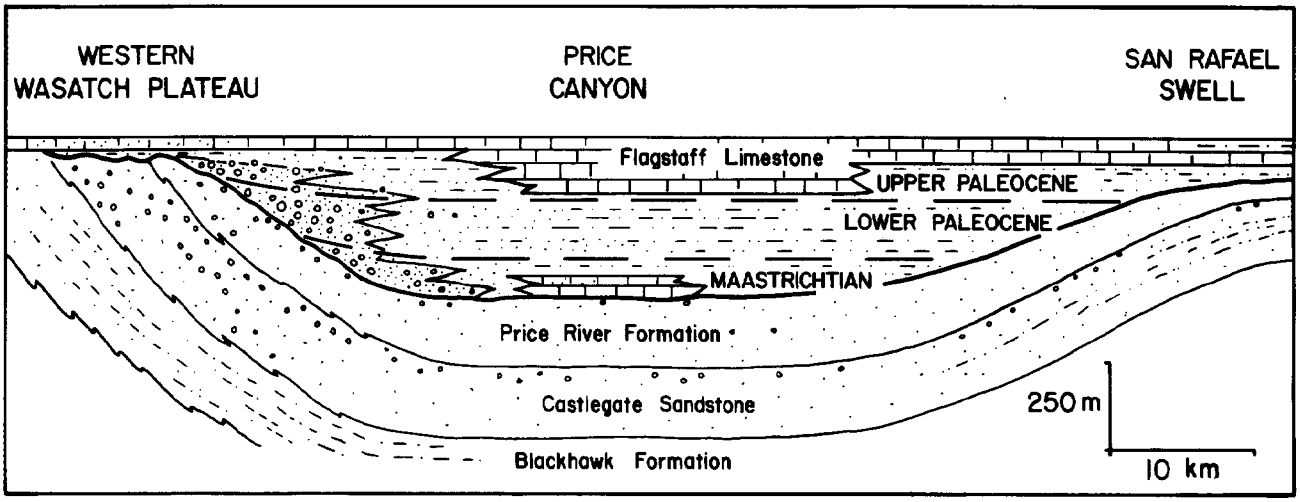

Figure 16—Schematic diagram of Maestrichtian-upper Paleocene onlap relationships within the North Horn Formation between the thrust belt and San Rafael Swell. Western half of figure is after Stanley and Collinson (1979).

terminated in latest Campanian time as deformation in the thrust belt waned and uplift occurred within the basin. Intrabasin uplift took the form of individual domes and arches over basement faults (Davis, 1978). Latest stages of folding in the thrust belt are interpreted to have been contemporaneous with uplift of the San Rafael Swell. Coeval, but spatially separate, thin-skinned and thick-skinned deformation is consistent with structural interpretations inferred from detailed sedimentologic study of the Hoback basin. This basin is situated between the Wyoming thrust belt and the Wind River uplift, which show overlapping periods of active deformation (Dorr et al., 1977). Both the thrust belt and the San Rafael Swell were onlapped by sedimentary strata of late Paleocene age.

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